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The Korea/Tsushima, Tsugaru, and Tatar Straits connect the Japan/East Sea (JES) with adjacent seas. Of the four straits, the Korea/Tsushima Strait (TKS) provides the vast majority of inflow into the JES and plays a major role in determining its dynamics. The heat and salt balances within the JES are in large part determined by the inflow through the KTS. Understanding of the relationships and forcing mechanisms of the inflow from the Yellow and East China Seas through the KTS is important for understanding the circulation of the JES. Ultimately, flow through these Asian seas plays an important role in determining the temperature and salinity characteristics of North Pacific circulation.

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Currents Through the Korea/Tsushima Strait

A Review of LINKS Observations

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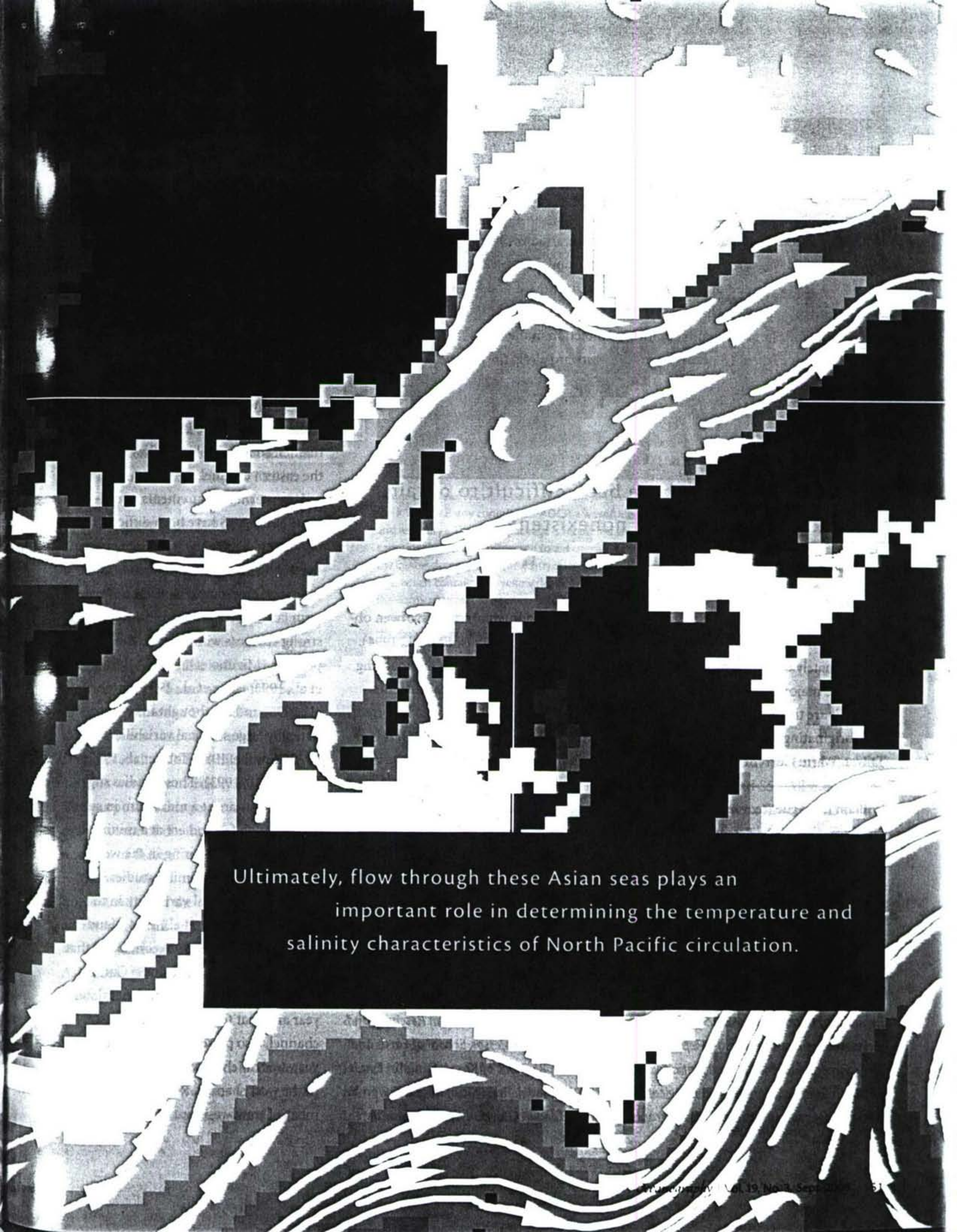
The Korea/Tsushima, Tsugaru, Soya, and Tatar Straits connect the Japan/East Sea (JES) with adjacent seas. Of the four straits, the Korea/Tsushima Strait (KTS) provides the vast majority of inflow into the JES and plays a major role in determining its dynamics. The heat and salt balances within the JES are in large part determined by the inflow through the KTS. Understanding of the relationships and forcing mechanisms of the inflow from the Yellow and East China Seas through the KTS is important for understanding the circulation of the JES. Ultimately, flow through these Asian seas plays an important role in determining the temperature and salinity characteristics of North Pacific circulation.



Ultimately, flow through these Asian seas plays an important role in determining the temperature and salinity characteristics of North Pacific circulation.

The KTS is a shallow channel (sill depth of about 140 m) that connects the broad, shallow East China Sea (depths between 50 m and 1000 m) with the much deeper JES (depths exceed 2000 m). The KTS is about 330 km long and 140 km wide at its narrowest constriction. The eastern end of the KTS is divided into east and west channels by Tsushima Island. The maximum depth of about 200 m in the KTS occurs near Tsushima Island in the west channel within a closed topographic depression approximately 60 km long and 10 km wide. The major current features in the strait are the warm Tsushima Current, originating from the Kuroshio and Taiwan Warm Current (Nitani, 1972; Beardsley et al., 1985; Fang et al., 1991), and inflowing from the East China Sea and outflowing into the JES (Chang et al., 2004); the Cheju Current (Chang et al., 2000), located between Cheju and Korea, and flowing into the western KTS; and a counter flow on the east side of Tsushima Island (Miita and Ogawa, 1984; Egawa et al., 1993). The current direction in the KTS is generally northeastward along the channel, but southwestward countercurrents have been observed (Katoh, 1994; Isobe et al., 1994). Tidal currents with speeds approaching 50 cm s^{-1} embedded in total currents of nearly 100 cm s^{-1} have been reported in the KTS by Isobe et al. (1994). It is well established that flow from the strait eventually takes two divergent paths in the JES. The Tsushima Current separates into two branches near the Japan and Korea coasts as it splits around Tsushima Island. One branch, the East Korean Warm Current, flows northward along the eastern coast of Korea. The second branch, the Nearshore Branch, flows eastward along the northern coast of Japan. The flow through the western channel of the Korea Strait sometimes forms the Offshore Branch along the Japanese coast following the continental slope, while the Nearshore Branch on the continental shelf is fed by the flow through the eastern channel.

Long-term measurements of currents in the KTS have been difficult to obtain and had been almost nonexistent...

Long-term measurements of currents in the KTS have been difficult to obtain and had been almost nonexistent due to the intense level of fishing and trawling (Kawatate et al., 1988). Short-term current observations have shown strong currents with large tidal components (Mizuno et al., 1989; Egawa et al., 1993; Isobe et al., 1994; Katoh et al., 1996) and are thought to be dominated by large seasonal variability (Yi, 1970; Kawabe, 1982; Toba et al., 1982; Egawa et al., 1993). These studies suggest currents are at a maximum in summer through fall and are at a minimum in winter through spring in the west channel. However, similar studies have found little seasonal variability in the east channel (Isobe et al., 1994). Studies by Egawa et al. (1993) concluded that the main axis of the Tsushima Current was in the west channel for the entire year and that the current in the east channel, also present throughout the year, was much slower than the currents in the west channel. Recent development of trawl-resistant bottom mounts

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(TRBMs) for Acoustic Doppler Current Profilers (ADCPs) has made long-term current measurements possible in the KTS. In a joint Japan/Korea/U.S. effort to study the East Asian Marginal Seas, the United States Naval Research Laboratory (NRL), as part of its Dynamical Linkages of Asian Marginal Seas (LINKS) program, deployed 12 ADCPs in TRBMs for 11 months in the KTS during 1999–2000 (Perkins et al., 2000a; Teague et al., 2002). These measurements formed one of the best long-term data sets ever acquired in the KTS. Numerous analyses have been made using these data. In addition to these moorings, a TRBM mooring was deployed west of Tsushima Island (Teague et al., 2002), another in the Cheju Strait (Chang et al., 2000), four TRBM moorings across the Taiwan Strait (Teague et al., 2003), and three additional TRBM moorings in the Yellow Sea prior to the KTS moorings (Teague and Jacobs, 2000). The bulk of the deployments were based on a new type of TRBM know as a Barny (Figure 1) because it was shaped like a barnacle (Perkins et al., 2000b), while the other TRBMs were commercially available. The purpose of this paper is to summarize some of the main results from analyses of these data focusing on the KTS observations, and to increase our understanding of the cross-strait current and transport distributions (Teague et al., 2005) through analyses of NRL's East Asian Seas (EAS) Navy Coastal Ocean Model (NCOM).

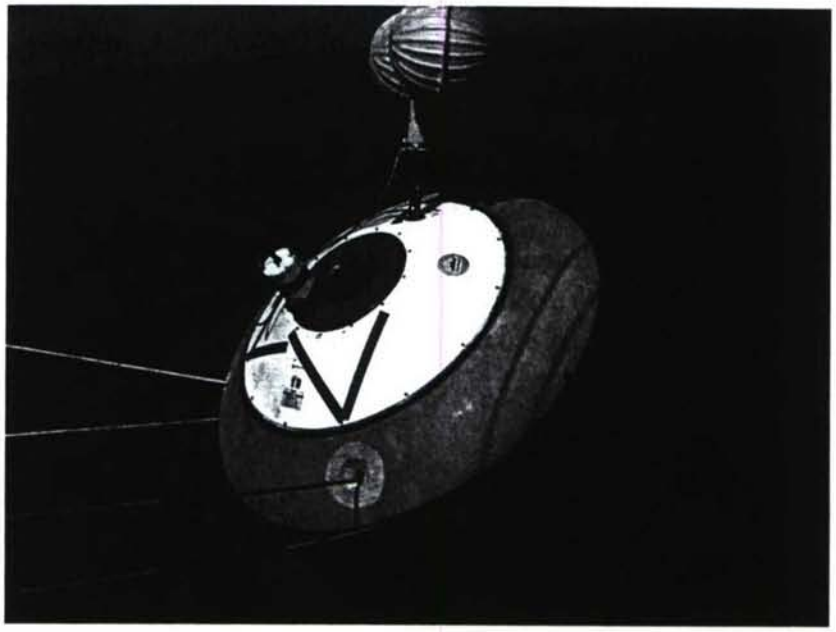

Figure 1. A trawl-resistant bottom mount referred to as a "Barny" is shown as it is deployed in the KTS. The Barny contains an ADCP, a wave/tide gauge, and acoustic releases (for relocation and recovery). The entire package is recovered via a pop-up float (center orange pod, which contains the ADCP) connected to a retrieval line. The gray and white cylinder attached near the center determines if the Barny is level on the bottom, prior to release. Both the mooring line, which contains the yellow floats, and the cylinder are retrieved prior to launch. Hence, the Barny rests on the bottom, relatively trawl-proof. Scraps of nets as well as trawl scrapings were found on the Barnys at instrument retrieval. There was no evidence of adverse impact on the data records due to the fishing activity.

DATA

Twelve moorings were initially deployed across the KTS in two lines in May 1999 (Figure 2). The moorings were divided equally in two lines that spanned the KTS, southwest (south line, S1–S6) and northeast (north line, N1–N6) of Tsushima Island. Eleven of these moorings were recovered, refurbished, and redeployed in mid-October 1999. N1 was not recovered and was suspected to be completely buried under mud. The location for N1 was moved about 10 km towards the southeast along the north line and a replacement mooring was deployed. An additional mooring was deployed just northwest of Tsushima Island (C1). Each of the moorings was in a TRBM and contained either an RD Instruments (RDI) 300 kHz Workhorse ADCP or an RDI Narrow band 150 kHz ADCP (N2, N3, and S5). All moorings contained Edge Tech Model 8202 acoustic releases for location and recovery. The head of the protected ADCP rested about 0.5 m above the ocean bottom. The ADCPs measured current profiles at either 15 or 30 minute time intervals with an accuracy better than 1 cm s^{-1} at a depth resolution of 2 m at moorings S1, S2, and N2, and a depth resolution of 4 m at the other moorings, starting at about 6 to 10 m off the bottom and extending to 5 to 10 m from the ocean surface. The moorings also measured near-bottom pressure and temperature.

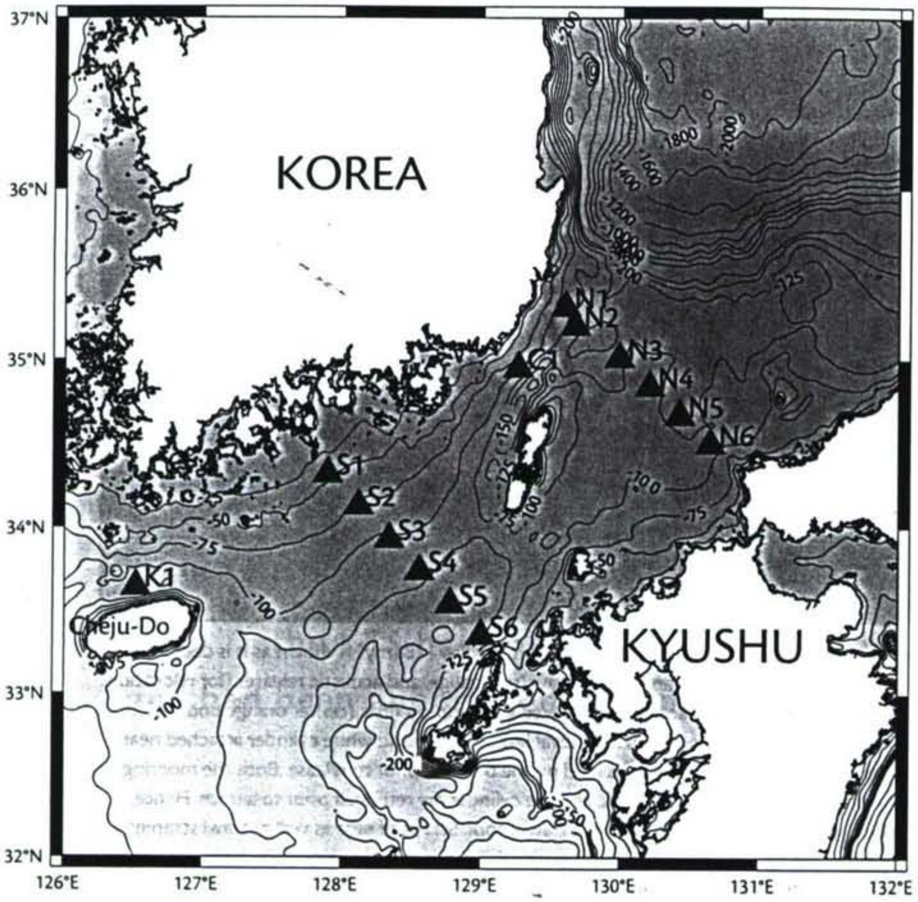

Figure 2. ADCP mooring locations and bathymetry (m) are shown for the Korea/Tsushima Strait located between the Republic of Korea and Kyushu, Japan. The Tsushima Current from the East China Sea and the Cheju Current through the Cheju Strait, located between Cheju-Do and Korea, provide the inflow into the Korea/Tsushima Strait. The inflow is split into west and east channels by Tsushima Island. Bathymetry is from a one-minute resolution data set available from the Laboratory for Coastal and Ocean Dynamics Studies, Sung Kyun Kwan University (Choi, 1999).

Evidence of trawl hits was found on all of the moorings on recovery. The KTS moorings are fully described by Teague et al. (2002). The Cheju Strait mooring (K1, Figure 2; March 1999 to December 1999) (Chang et al., 2000), the Taiwan Strait moorings (October 1999 to December 1999) (Teague et al., 2003), and the Yellow Sea moorings (July 1995 to January 1996) (Teague and Jacobs, 2000) are similar in design to the KTS moorings.

REVIEW OF SOME MAIN RESULTS

Yellow Sea Warm Current

Prior to the Tsushima Current flowing through the KTS, historical analyses have suggested that there was a branching of the Tsushima Current into the Yellow Sea Warm Current (YSWC) and a northward penetration into the Yellow Sea (Uda, 1934; Nitani, 1972). However, the Tsushima Current has been shown to not penetrate into the Yellow Sea interior during winter (Hsueh, 1988; Teague and Jacobs, 2000). The onset of the YSWC was directly observed using measurements of current profiles, near-bottom temperature, and pressure from the Yellow Sea moorings (Teague and Jacobs, 2000), in conjunction with the wind climatology from NOGAPS (Navy Operational Global Atmospheric Prediction System) (Hogan and Rosmond, 1991; Rosmond, 1992; Hogan and Brody, 1993). During fall and winter monsoon periods, strong northerly (i.e., southward) wind bursts drove a north-to-south rise in pressure in the Yellow Sea and correspondingly forced a northward flow in the Yellow Sea trough. During summer, there was a weak northward flow that resulted from southerly (i.e., northward) winds. The branching of the Tsushima current may only have extended to the north as far as Cheju, and the measurements suggested that there is a clockwise flow around Cheju. Therefore, the YSWC was not a branching of the Tsushima Current and hence the Tsushima Current does not branch off into the Yellow Sea.

Tsushima Current

Using observations from the KTS concurrent with measurements from the Cheju and Taiwan Straits, and temperatures and salinities from the Modular Ocean Data Assimilation System (MODAS) climatology (Fox et al., 2002), we investigated the circulation of the East China Sea and origin of the Tsushima Current (Teague et al., 2003). Volume, temperature, and salinity transports were computed for each strait and evaluated for the October to December 1999 time period. Average volume transport was 0.14 Sv through the Taiwan Strait

into the East China Sea, about 0.59 Sv eastward through the Cheju Strait, and 3.17 Sv through the Korea Strait into the JES. Salt and heat transports through the Korea Strait and into the JES were 110.5×10^6 kg s^{-1} and 0.24×10^{15} W, respectively. Heat loss in the East China Sea was approximately 200 W m^{-2} while only about 10 W m^{-2} was estimated lost in the Yellow Sea. Winds affected the transports in each of the straits. Most noticeable wind effects were observed in the Taiwan Strait where strong north wind events forced flow reversals into the South China Sea. The flow through the Korea Strait was formed by the Taiwan Warm Current and Kuroshio waters, which may have been modified by Yellow Sea, East China Sea, and South China Sea waters, and by river outflows. The main source for the Tsushima Current was clearly the Kuroshio during fall 1999. Isobe (1999) also found that transport through the Taiwan Strait was small during the fall time period and similarly suggested that the origin of the Tsushima Current was from the Kuroshio for this period. However, he concluded that the Tsushima Current originated from the Taiwan Strait via the Taiwan Warm Current for the rest of the year.

Tides

Measurements from the KTS moorings allowed for analyses of the complex nature of the tides and tidal currents that were embedded in the strong Tsushima Current (Teague et al., 2001; Book et al., 2004). Both current and pressure measurements were used for determining the cross-strait and vertical tidal structures. Some significant differences in tide amplitudes and phases with tide-chart values were found. The tide range was over 3 m along the south line but only about 0.7 m along the north line. Maximum total current velocities exceeded 100 cm s^{-1} in the surface layers and typically exceeded 50 cm s^{-1} at mid-depths along both lines. These data were analyzed for eight tidal constituents, which accounted for about 88 percent of the sea surface height variability along the south line and 70 percent along the north line. M2 (lunar semi-diurnal), S2 (solar semi-diurnal), K1 (lunar-solar declinational), and O1 (lunar diurnal) were the dominant constituents. Their amplitudes were generally 10–20 percent smaller than amplitudes from tide charts. M2 tidal velocities ranged from 18 to 27 cm s^{-1} along the north line and were largest at N1, the mooring closest to Korea. Along the south line, either M2 or K1 dominated the tidal contribution to the current, with tidal velocities that ranged from 13 to 23 cm s^{-1}. Tidal velocities were fairly depth independent at mid-depths but exhibited varying degrees of depth dependence in the near-surface and near-bottom layers. While tidal currents were responsible for about 25 percent of the eddy kinetic energy in the near surface layer, they accounted for more than 50 percent of the eddy kinetic energy at mid-depths and for about 70 percent near the bottom. Additional analyses were made using a linear barotropic (depth-independent) data assimilation model that very accurately predicted surface heights within 0.5 cm near the moorings and within 1 to 4 cm elsewhere in the KTS (Book et al., 2004). The tides in the KTS exhibited a complex structure in which the diurnal (daily) constituents had stronger currents relative to their sea-level-height ranges than the semi-diurnal (twice-daily) constituents. No single constituent dominated both tidal heights and velocities in all parts of the KTS. In general, reconstruction of tidal heights in the KTS require, in order of importance, M2, S2, K1, O1, and N2, while reconstruction of the tidal velocities require, in order of importance, only M2, K1, S2, and O1.

Inertial Oscillations

There was a strong inertial oscillation (IO) (anticyclonic motion with a period of about 21 hours for this region) response to the wind stress during summer 1999 (Jacobs et al., 2001). A similar response of the same order of magnitude was expected during the winter. However, the IO response in winter was much weaker than predicted by a simple linear model. Inertial oscillations within the KTS generated a velocity structure

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during summer in which the currents within the mixed layer and below the mixed layer were of comparable amplitudes but in opposite directions. The depth at which the currents reversed directions depended on the mixed-layer depth and varied throughout the year, ranging from about 40 m during summer to near the bottom in November. Typical IO amplitudes ranged between 10 and 20 cm s^{-1}. Although winter wind events were of comparable magnitude and frequency to summer wind events, there was a noticeable absence of IO activity in winter. During winter, current velocities were more uniform with depth and the currents were in the same direction throughout the water column. The difference in IO activity between summer and winter was due to the change in stratification. Strong summer stratification prevented the wind-stress momentum from mixing downward and allowed for a surface flow toward the boundaries with a subsurface return counter flow. The lack of stratification in winter allowed wind-stress momentum to mix downward and was not conducive for IOs to develop.

Bottom Cold Water

An intrusion of bottom cold water into the northwestern KTS, originating from the JES, was observed using temperature measurements made concurrently with the current measurements on the north line on the western side of the KTS (Johnson and Teague, 2002). This bottom cold water, often referred to as Korea Strait Bottom Cold Water (KSBCW), has been of considerable interest to regional oceanographers who have sought to understand its physical characteristics and seasonal variations (e.g., Cho and Kim, 1998). There have been relatively few current observations simultaneous with temperature observations. From analyses of our measurements, in contrast to previous work, a yearly cycle in the KSBCW appearance was not observed in the bottom temperature records. Rather, sustained intrusions occurred in May through June and again in December through January. Bottom currents during the times of its appearance showed only limited advective intrusion with recycling back to the JES. During low-temperature episodes, bottom currents were directed toward the Korean coast on the west side, and toward the coast of Japan in the middle and mid-eastern side of the Strait. These bottom-current directions gave the appearance of a short advective intrusion and a recirculation back into the JES. The bottom cold-water intrusions could be the product of relatively weak advection augmented by horizontal tidal diffusion. Monthly scale bottom-temperature records in the intrusion area were negatively correlated with the cross-strait bottom pressure anomaly, a measure of geostrophic transport through the Strait. Analyses of our measurements suggested that when geostrophic transport was low, the bottom cold water intruded; when transport was high, the cold water did not intrude. Prediction of the bottom cold-water appearance could thus be based upon the geostrophic transport.

Low-Frequency Currents

Currents in the KTS were examined for processes having time periods longer than two days (Teague et al., 2002). A high-velocity current core existed at the south line along the western slope of the KTS for the entire recording period. Peak non-tidal currents exceeded 70 cm s^{-1} while total currents exceeded 120 cm s^{-1}. Countercurrents were common near the coasts along the south line and near the middle of the strait along the north line in the lee of Tsushima Island. The north line was marked by strong spatial variability and a large seasonal signal, but the mean consists of two localized intense flows concentrated near the Korea and Japan coasts. The location of the current bifurcation upstream of Tsushima Island is unknown. However, the mean flow directions along the south line and similarities in velocity distributions between mooring C1 and S3 (less so with S4) suggested that the flow through S1, S2, and S3 continued on west of Tsushima Island while the flow at S4, S5, and S6 continued on east of Tsushima Island (Figure 2). Such a flow pattern corresponded to a larger transport on the western side of Tsushima Island, consistent with transports reported by Kaneko et al. (1991) and by Katoh et al. (1996).

Seasonality in the currents along the south line was weak while seasonality along the north line was stronger. Very little seasonality was observed near the current core at mid-depth at S3. Near-surface layer currents along the north line were larger and were more highly variable in the summer and fall months. Currents at mid-depths were smaller and less variable but similar to the near-surface flows along both sections. Flows near the bottom were smaller but similar to those at mid-depth except at N1, N2, and N6 where larger velocities were found during the spring season. A more concentrated outflow along the north

line from the east and west channels could have magnified smaller variability in the main velocity core observed along the south line. EOF (empirical orthogonal function) analyses indicated that the seasonality may have been driven in summer by the larger current variability on the Korea side of the strait, while in winter the current variability was more uniformly distributed across the KTS. Interannual variations were unknown and could have caused significant departures from this one measurement of the seasonal flow.

Average Annual and Seasonal Transports

Total transports across the KTS and in the east and west channels have not previously been well determined, despite the many measurements of currents by direct and indirect methods, because most of these measurements were short term and were limited geographically. Our long-term ADCP measurements across the KTS have provided a unique opportunity to estimate accurately the transports across the KTS over an annual cycle (Teague et al., 2005). The total average transport through the KTS was 2.65 Sv from May 1999 through March 2000. The average transports split into west and east channels were 1.46 Sv and 1.19 Sv, respectively. Highest transports occurred during fall and lowest transports occurred during winter. Transports were surface intensified and depth dependent in summer and fall while during winter and spring transports were nearly homogeneous in depth. Generally, about half of the transport in the KTS was contained in the upper 50 m and about 10 percent of the transport occurred below 100-m depth. Transport was larger in the western channel than in the eastern channel except during August and December. The Tsushima Current separated around Tsushima Island over a region about 31-km wide along the south line, on average about 127 km from Korea (33.80°N, 128.49°E). A wake zone, averaging about 40 km in width, was located downstream of Tsushima Island and was a region of low transport and high variability. The island wake formed when the transport was large. Eddy formation in the wake zone can give the false appearance of a triple branching just downstream of Tsushima Island.

Since March 1998, voltages induced by the Tsushima Current through the KTS have been monitored using a submarine telephone cable located north of Tsushima Island between Pusan, Republic of Korea, and Hamada, Japan. A good linear relationship between cable voltage and the transport measured by the KTS moorings was determined (Kim et al., 2004). Hence, transport variations through the KTS can now be estimated more accurately than ever before for the time period in which voltage data were collected. The voltage-derived transports have revealed many temporal variations on scales ranging from less than a week to interannual periods. The cable voltage measurements can provide a reliable means of continuously monitoring the volume transport of the Tsushima Current. *In situ* data such as the those from the KTS moorings were required for accurate calibration of the voltage data.

Synoptic Forcing of the KTS Transport

Transport variations through the KTS in the synoptic frequency band (periods of 2–20 days) were examined using results from a three-dimensional primitive equation model, satellite observed sea-level variations, a linear barotropic adjoint dynamic model, and the KTS mooring observations (Jacobs et al., 2005). The adjoint results showed that the transports were sensitive to the wind stress over the JES but not over the Yellow and East China Seas. Satellite and three-dimensional model analyses indicated a sea-level response to wind stress along the east coast of Korea that propagated towards the KTS and changed the sea-level slope across the strait, thus altering the geostrophic transport through the strait. Strong southerly (i.e., northward) winds produced a sea-level set down along the east coast of Korea and a sea-level increase along the shelf break. The set-down propagated towards the KTS as a Kelvin wave (a coastally

These measurements formed one of the best long-term data sets ever acquired in the KTS.

trapped long gravity wave that traveled southward along the east coast of Korea) and increased the transport through the strait. Similarly, northerly (i.e., southward) winds produced a set up along the Korea coast and decreased the transport. The wind stress affected the transport within time scales of four hours according to barotropic dynamics, but the slow development of atmospheric forcing on the order of 1–2 days modulated the response. Wind stress over the Yellow and East China Seas did not significantly affect the transport because the Kelvin waves would propagate away from the strait.

...high-resolution current measurements made in the KTS have greatly enhanced our understanding of the current flow through the strait on time scales ranging from tidal to seasonal.

Applicability of Barotropic Approximation Using Variation Assimilation

To investigate the importance of baroclinic (depth-dependent) processes in the KTS, a variational assimilation technique was used to combine velocity and sea-surface height anomaly measurements with a system of dynamics to estimate the seasonal flow (Smith et al., 2005). This approach was used to obtain a solution that best fits prescribed dynamics and measurements in a weighted least squares sense. The accuracy of the barotropic approximation was tested in the KTS. It was found that the best-fit solution did not satisfy the assumed dynamics within expected values at the exit of the west channel during fall. The barotropic results produced an unrealistic East Korea Warm Current that was too weak during fall and almost absent during summer and winter. The assimilation of measurements within a baroclinic system of equations resulted in a significant reduction in momentum error at the exit of the western channel during fall. This reduction implied that there was a failure of the barotropic approximation within this region and that other processes are prevalent in the western channel that can affect the dynamics, such as the KSBCW intrusion.

MONTHLY TRANSPORT DISTRIBUTION ACROSS THE KTS

Average annual transport sections along the north and south lines, and total transport for each line as a function of time for the KTS moorings have been presented by Teague et al. (2002, 2005). This work will be extended here in analyses of monthly averaged transport sections in conjunction with modeled currents and salinities from NRL's EAS NCOM. Tidal semi-diurnal and diurnal frequencies were first removed from the current records by using a 40-hour half-power point low-pass filter. Velocities were then rotated (42.5°) to obtain the along strait velocity which was approximately normal to the mooring lines. An optimal interpolation (OI) scheme (Bretherton et al., 1976; Lorenc, 1981) was used to interpolate the ADCP observations horizontally and vertically along each mooring section. The average spacing between moorings was 25 km and velocities were measured about every 4 m in depth. Velocities at 12-hour resolution were interpolated to a 5-km horizontal by 4-m vertical grid-cell resolution. These data resolved most current features on the typically observed horizontal length scales of 15 to 30 km and on vertical length scales of about 20 m near the bottom, decreasing towards the surface. Transport estimate errors based on the horizontal and vertical length scales were about 0.5 Sv. The total transport across each line was the integral over the cross-sectional area of the velocity normal to the section. The transport calculations have been described in detail by Jacobs et al. (2001) and by Teague et al. (2005).

Monthly averaged and annual-averaged transports (May through March) are shown at grid-cell resolution for the south line in Figure 3. The annual-averaged transport distribution (lower-right panel) for the south line was not closely mirrored in individual monthly averages, except for the center of the high-velocity core at mid-strait, approximately centered on the down slope to the sill and

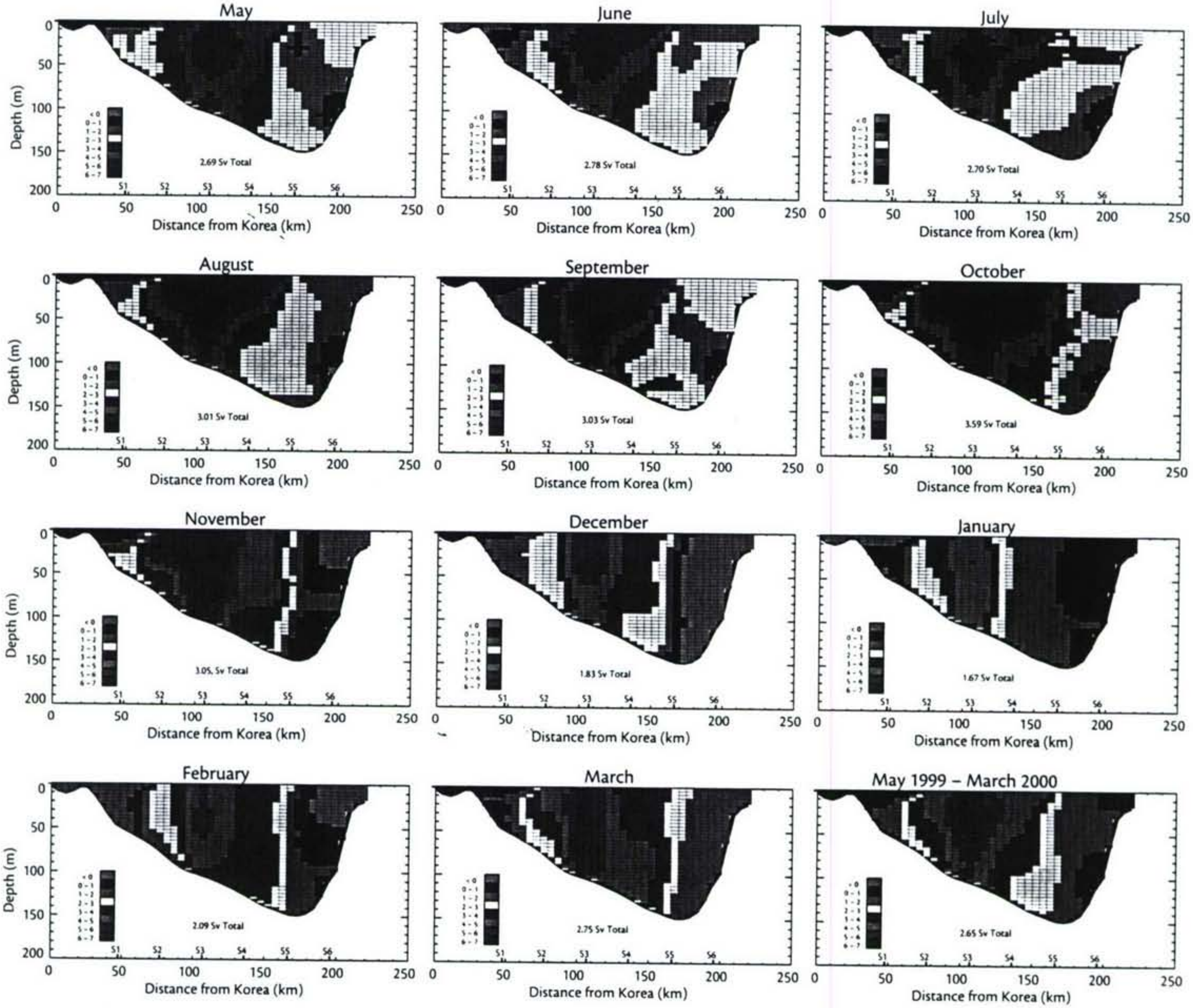

Figure 3. Shown are the south line's monthly averaged transports for May 1999 through March 2000, and averaged transport for May 1999 through March 2000. Units are $10^3 m^3 s^{-1}$ or 1×10^{-3} Sv. Each grid square is approximately 5-km across strait by 4 m in depth, except near the bottom where the depth dimension may be less. Positions of moorings S1 through S6 are indicated on the x-axis.

located about 110 km from Korea. For high-velocity core transports defined by minimum grid-cell transports of 5×10^{-3} Sv, the core was about 40 km in width in the annual averaged transports, but failed to surpass this minimum value in January when total transports were smallest. The core had a maximum width of 90 km in October when total transports were largest. The intensity of the core generally decreased with depth except for July. Negative transports associated with counter currents were observed off the coast of Korea in January, February (largest, extending to 60-m depth), and June. Counter currents off the coast of Japan were observed in November, December (largest, extending to

150-m depth), and February.

Transports are shown for the north line in Figure 4. Total transports for the north and south lines should be nearly identical, but were generally lower on the north line, likely due to omission of intense currents commonly found near the Korean coast. Because the transport through the east channel is believed to be adequately resolved, the total transport through the west channel was estimated as difference between the total south line transport and east channel transport. Total transports through the east and west channels are indicated in Figure 4 for each month. The annual-averaged transports have some similarities to the monthly averaged transports in June and July. The most intense flows, but not always the largest total monthly averaged transports, were generally concentrated in the west channel from September through November. However, in August, total monthly transport was larger in the east channel. Negative transports associated with counter currents in the lee of Tsushima Island (located approximately between N3 and N4) were observed between June and December, and in the annual-averaged transports. Counter currents were maximum intensity in November and, at about 80 km from Korea, extended over nearly the entire water column. A subsurface core of negative transports between about 30 and 90 m had occurred in December. The negative transports had appeared to require relatively large current velocities and hence large transports in both east and west channels. Negative transports were also observed near the bottom on the west channel side on the downslope off Korea during November through January. These transports were associated with an intrusion of bottom cold water (called Korea Strait Bottom Cold Water, KSBCW) from the JES, which appears on the western side of the KTS in winter (Cho and Kim, 1998). Johnson and Teague (2002) reported on this cold intrusion from previous analyses of these data; they also observed sustained intrusion in May and June, which was not apparent in the monthly averaged transports.

...many studies remain to be done with these data, such as determining the connectivity of the processes observed in the KTS with processes in the JES and the nature of low-frequency flows and transports.

A geographical map of monthly averaged surface currents and salinity was produced for the KTS using NRL's EAS model (Figure 5) for 2005. Although the model time period was different than the time period for the *in situ* measurements, the current patterns though the KTS for 2005 are believed to be representative and are now used to help interpret the transport sections shown in Figures 3 and 4. The modeled currents show the Tsushima Current and Cheju Current flowing through the KTS and bifurcating around Tsushima Island. The Tsushima Current is most intense during the summer and fall, in agreement with the observations. Saline waters, likely originating from the Kuroshio, flow through the Taiwan Strait, wrap around Cheju in the fall and winter period, and help form the Cheju Current. In addition, in winter, a tongue of high-salinity water extends into the Yellow Sea, but the surface currents do not indicate that this intrusion is a branching of the Tsushima Current. The dynamics of this tongue are controlled by the pressure gradients set up during the winter monsoon (Hsueh, 1988; Teague and Jacobs, 2000).

The modeled fields suggest that the large transports measured along the south line during August through November were due to large inflow from the Tsushima Current combined with increased inflow by the Cheju Current through the Cheju Strait from the Yellow Sea. The average model transport over five years of 3.1 Sv (rms of 0.7 Sv) is larger than our measured transport average of 2.65 Sv (rms of 0.9 Sv) for May 1999 through March 2000. The smaller transport could be due to omission of high-velocity currents near the coasts and near the surface. The counter currents observed on the eastern side of the south line, most apparent in December, were caused by a recirculation of the Tsushima Current through the south line that is likely affected by the anticyclonic

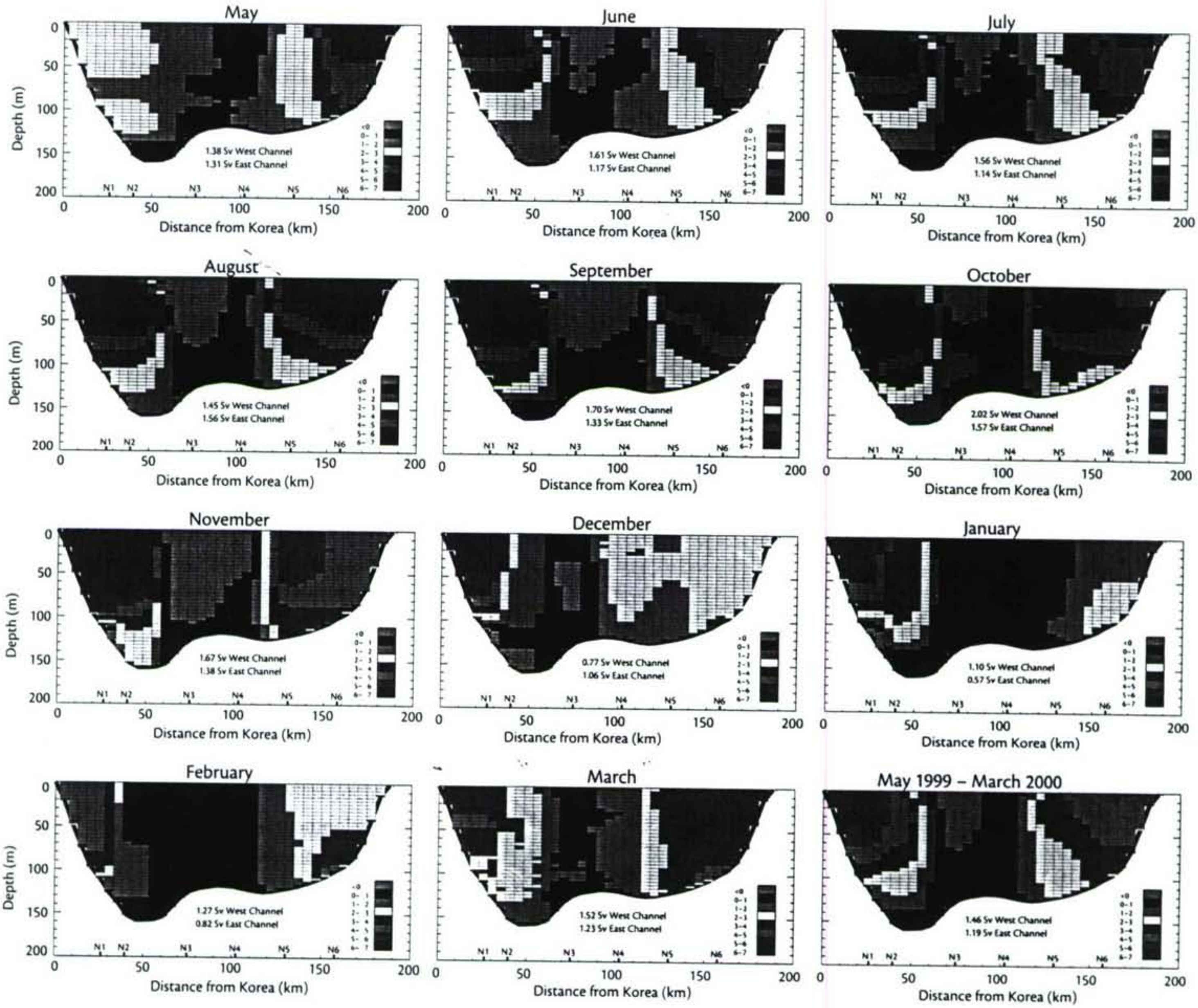

Figure 4. Shown are the north line's (N1–N6) monthly averaged transports for May 1999 through March 2000 and averaged transport for May 1999 through March 2000. Units and dimensions are the same as in Figure 3. Total transports for the north and south lines (south lines shown in Figure 3) should be nearly identical, but were generally lower on the north line, likely due to omission of intense currents commonly found near the Korean coast.

eddy that periodically forms off Kyushu. Although the resolution of the model was not adequate to capture the counter current in the lee of Tsushima Island, eddy activity is suggested that could cause the counter flows.

SUMMARY AND CONCLUSIONS

These high-resolution current measurements made in the KTS have greatly enhanced our understanding of the current flow through the strait on time scales ranging from tidal to seasonal. However, many studies remain to be done with these data, such as determining the connectivity of the processes observed in the KTS with processes in the JES and the nature of low-frequency flows and transports. Higher-frequency processes (i.e.,

ports and their distributions across the entire KTS as well as in both east and west channels.

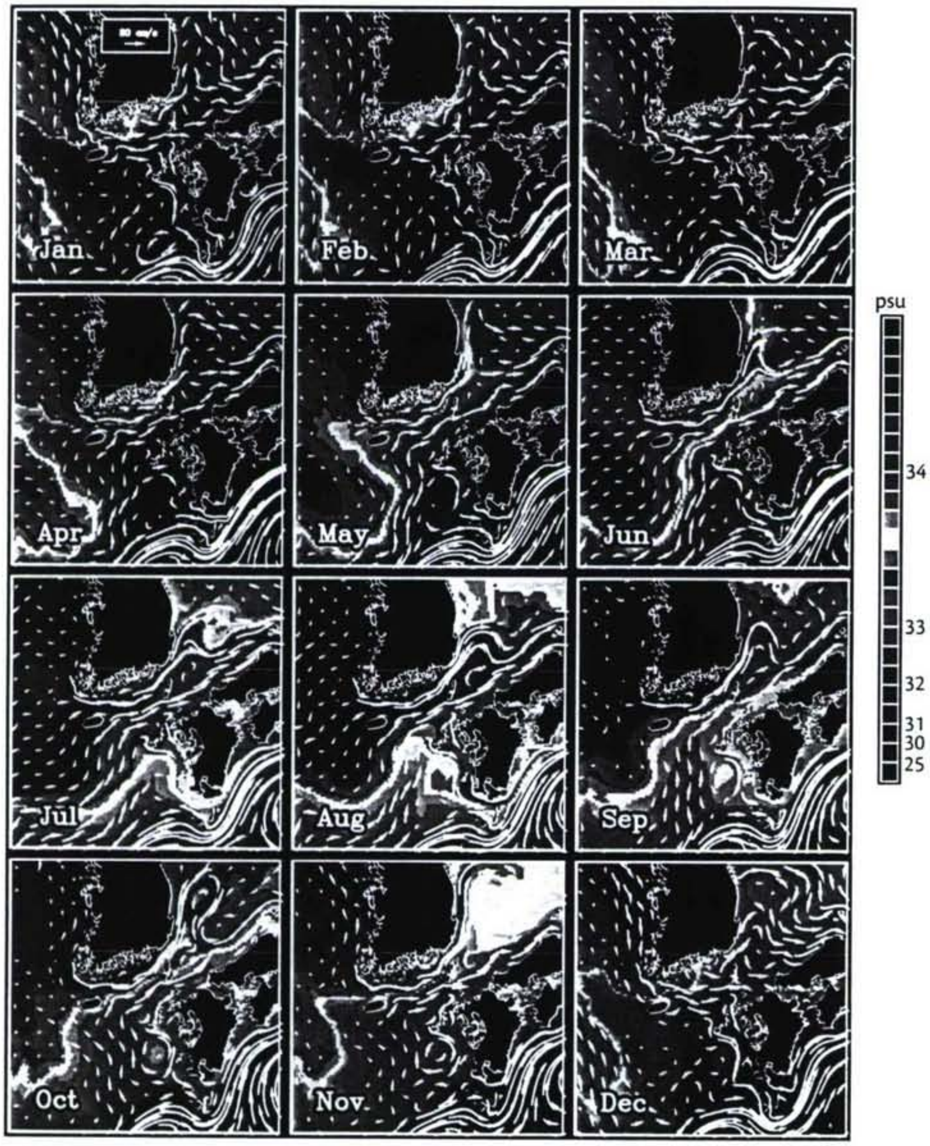

Figure 5. Monthly average surface salinity with monthly averaged surface current vectors superimposed on NRL's East Asian Seas (EAS) Navy Coastal Ocean Model (NCOM) for 2005. Current patterns though the KTS for this year are believed to be representative and are now used to help interpret the transport sections shown in Figures 3 and 4.

below tidal frequencies) have not yet been examined using these KTS ADCP measurements. Additional transport analyses made here show that the transport distribution across the strait varies greatly from month to month, both upstream and downstream of Tsushima Island, and that the annual mean cross-strait transport distribution may look very different from an individual month. Inter-annual variability, as shown by long-term submarine telephone cable voltage measurements, is expected to significantly alter the annual mean trans-

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